PROGRAM OF RESEARCH ON THE MANAGEMENT

OF RESEARCH AND DEVELOPMENT

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Evanston, Illinois

PEOPLE, MODELS AND R AND D ORGANIZATIONS

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June, 1966

ABSTRACT

The definition of concepts dealing with scientific manpower in R and D societies leads to the analysis of models and their use in the collection and analysis of data. The use of simulation as a tool to study R and D societies is considered. Different languages for the study of R and D societies are classified, compared and evaluated. This paper will appear as a chapter in The Research Society, edited by Maynard W. Shelly, II.

This paper was prepared with the support of the Office of Naval Research (ONR) and the National Aeronautics and Space Administration (NASA) (Grant NSG-495).

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PEOPLE, MODELS AND R AND D ORGANIZATIONS[1]

Human organizations have been and continue to be studied by many disciplines and with numerous techniques. The R and D society represents one of the most complex of these organizations. Approximately 600 researchers have indicated current activities dealing with the R and D process (COLRAD, 1964), their techniques centering around empirical studies in individual organizations, and theoretical studies of the way in which R and D should be carried out. Certain aspects of R and D societies suggest that the use of several types of models, combined with computer simulation, promise to yield major assistance to this field of research. The complexity of the R and D societies, the stochastic nature of many influences, and the rapidly changing environment make this approach especially promising. Of primary interest is the movement of the people who represent a major component of these activities. The "open loop" characteristics of the R and D society adds great uncertainties to the researchers' problem, as well as to the researchers in the society under scrutiny. The effects of specific instances: a new discovery, the price increase of a commodity, or the availability of new people will influence the behavior of the R and D society. These influences are held mostly at the individual or small group level, requiring a viewpoint which scrutinizes the individual components. The chapter will develop discussions of the types of models and simulations which seem promising in meeting this need, concentrating on the people involved in an organization and some of their characteristics.

People, facilities and "knowledge" are key resources of all research and development communities. Of the three, people are the most significant and critical resource. People are necessary to design, construct, modify and operate facilities. People are the main instrument for the production, transmission and retrieval of "knowledge." Economic wealth makes it possible to recruit, hire, develop, and support these people and to purchase facilities. Undeniably, a set of objectives or purposes is also important, and a good "reputation" makes it easier to attract personnel. Because organizational factors may have major effects on human productivity and greatly affect the utilization of human endeavor, the complete understanding of human organization, and especially of the complex R and D organization, will ultimately require the integration and understanding of all the aforementioned factors and many others.

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[1] This paper was prepared with the support of the Office of Naval Research and the National Aeronautics and Space Administration (Grant NSG-495). The author wishes acknowledge the assistance of Donald Bloch of the Special Operations Research Office, American University; Michael Boyaval of the Raytheon Company for assistance in the development of the discussion on models; Anthony Chien, Dennis Gensch and Stephen Kennedy, who developed the SIMSCRIPT formulation of the problem; and Joy Zweigler for her able editorial assistance.

Varying characteristics of people are important in order to understand and to predict the behavior of R and D organizations. Because individual differences are great, many factors can influence the behavior of researchers. Scientists and engineers may be described for our purposes with a very large set of behaviors, all the way from computing the estimated weight of a sample on a slide rule, programming a Bessel Function subroutine in Algol, sterilizing a container, or proving a theorem, to delivering a paper. A taxonomy of behaviors should be developed, such that similar behavior may be identified even if carried out in different fields.

A skill[1] will be defined as a set of behaviors which a person performs over time and which are correlated with a scientific or engineering discipline. To be active a skill must be exercised, and the necessary facilities must exist to support the behavior. A potential skill exists if a person has acquired the skill (through training or experience) and if a measurable probability exists that he can exercise it if required.

The capability[2] of an R and D laboratory will be defined by the number of skills actively used by the required number of people engaged in the desired scientific or engineering activity, using the appropriate facilities. A potential capability may be defined by the ability of an organization to acquire the needed personnel (trained, experienced and/or having the proper prerequisites to training), as well as the other resources. An R and D organization demands different capabilities with a fixed or slowly changing set of skills. The characteristic of changes in demand is that they be fast (virtually over night), far-reaching (most of all the activity) and fundamental (a completely different discipline as opposed to a related one). Obviously, organizational policy could dictate, maximize or minimize the change in capability. The problem statement centers around the way in which one can predict and achieve a required change in capability. In many instances, the knowledge of existing capability contaminates the decision regarding direction and amount of change in capability desired (e.g., Let us stay in the steam locomotive business, as we have one of the best engineering teams). Because organizations have a strongly conservative tendency, they are usually biased in the direction of minimizing perceived change.

Another related problem occurs as a research program or development project progresses through its many phases. In the early stages of an R and D project, designing, planning and high level technical skills are required. Once the original conceptual solution and planning have been accomplished, many technical problems must be solved. Once the prototype equipment has been designed, or the research methodology and apparatus have been established, a new set of skills (usually of less complexity and technical quality) is required. If the project extends over a long period (e.g. for five (5) or ten (10) years), one may find that many of the skills used in planning and developing the conceptual solution are missing as people have left. The skills required to develop new R and D projects are

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[1,2]This concept was presented in expanded form by Rath and Rubenstein (1964).

different from those required to detail out, conclude and synthesize them. If a change in skills occurs, the acquisition of new projects is difficult, and redirecting one's effort into areas requiring a new capability is even more difficult, as there is a high sunk cost (personal and physical) which, whether appropriate or not, leads to a reluctance to implement the change.

The whole matter is complicated further in that a person may have several skills. One may either retrain a person if he can acquire enough useful skills or lose him by firing him or laying him off if enough useful skills are not apparent. The prospect of being faced with a personnel acquisition program through which one may hope to improve the organization's capability may be less pleasant than that of retraining and reorganization.

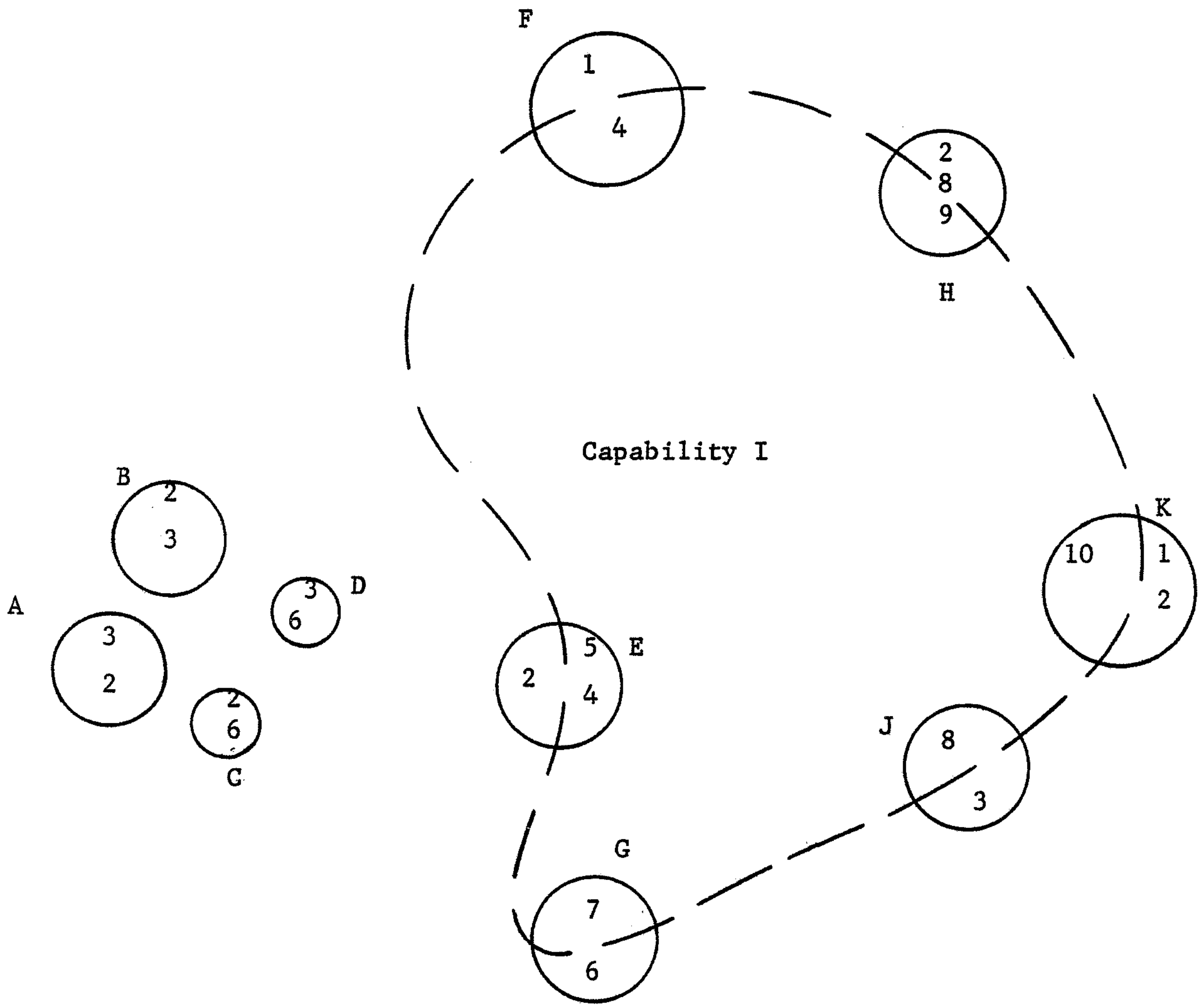
The basic manipulable unit is a person; the desired unit is a capability. The common elements are skills. These concepts are illustrated in Figure 1.

An illustration of the relationships between skills, capabilities and people is shown in Figure 1. People (A, B, C...) may be part of a given capability (I, II...III) or not. Capability I, for example, requires that certain skills (e.g., 4,5,7,8,9,10) be present. These skills are acquired by assigning people who have the skills (in this case E,F,G, H, J, and K). If one were hiring, one might be much better satisfied with two people (like L and M) as shown in Figure 2.

The capability requirements change as a function of time. Tannenbaum _et al_. (p. 179, 1961) presents an example of time dependent organizational change. In the early meetings of the T-group, problem solving is attempted, for example, in the first meeting of a Management Team session; "...a discussion of office memos..." and "talk about lines of authority" are typical concerns (Tannenbaum, _et al_., p. 179). In the later stages the concern is no longer the job, but themselves, "learning to be sensitive ..." and "seeing each other differently." (Tannenbaum, _et al_., p. 186, 1961). A similar change seems to occur as organizations age, moving from a product to an interpersonal orientation. A time recording of group composition would show skills changing, as well as people. The process of radical change, or spin-off, will not be covered here.

Because the changing of the composition of skills decreases the differences in an organization, R and D, being a complex process, cannot exist in an organization which does not require several existing, different and active capabilities. Cataclysms such as break-up and reorientation or even complete eradication have been recognized in the history of R and D groups. This high frequency of disastrous occurrences plus the newness of R and D have led to a new class of problems to be defined, problems observed most frequently in universities, usually at the department or school level. More recently these new problems have been occurring in industrial and military laboratories and R and D complexes.

The process of R and D, in most instances, progresses from a general conceptual and problem-solving level to a specific detailing of the solution. One formulation of this process has been generated within the



1,2,...i...skills

-----------capability I, II---

___________people A, B, C---

Figure 1

An illustrative diagram of 10 people with 10 skills, with one capability which requires the skills.

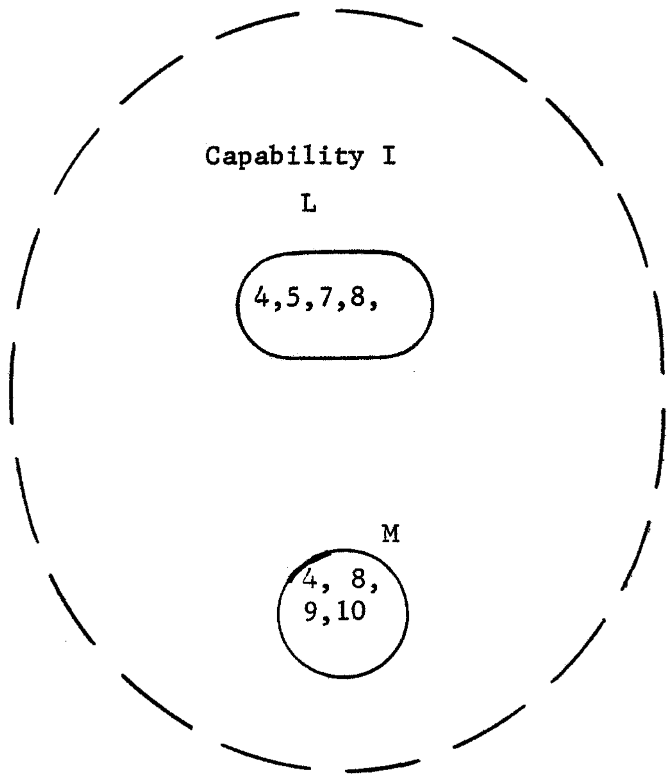


Figure 2

An illustrative diagram of 2 people with 6 skills.

Department of Defense (AFSCM 375-1, 1964). Three phases have been recognized: conceptual, definition and acquisition (engineering and production). Because each phase specifies what the next phase will do, the earlier phases require a higher-level set of skills. The conceptual phase requires both basic research and planning. The definition phase requires much systems engineering. The acquisition phase requires a great quantity of detailed engineering, followed by production engineering at a lower level.

The survival of the R and D organization depends upon active, existing and different capabilities, but the change from technical to service orientations and high level to low level personnel decreases the alternatives available. Differences between people are greater at the high technical level than at the lower levels. The changes in the organization lead to the attraction and retention of lower level, less technical and more similar personnel. Individuals with similar backgrounds, experience and training are more apt to communicate in terms of the social reinforcements which shift emphasis from the technical interaction of professionals to the human relations interactions of friends (Blau and Scott, p. 138, 1962). The concern of the personnel is geared more to "Will he like this information?" than "Is it something I really need?" For example: In an organization with an exceptionally low turnover, accomodation between colleagues must be very high. When the main reason for leaving is based on family (home) dissatisfaction, work conflicts cannot be too severe. A changing organization, where the skills levels are being lowered, can be recognized by the recruiting level of aspiration, the area covered by recruiters and recruiting success. The success in recruiting which may come from hiring lower-level-compatible personnel is quite different from the achievement of building a high-level, heterogeneous group. The factors of self-selection and external selection accelerate the development of a homogeneous, demographic population. A series of informal, open-ended interviews were carried out to determine some of the characteristics of an R and D society, and these resulting statements must be used in planning a formulation or description. The interviews yielded a set of perceived operational rules used in an R and D society, which may be considered as policy statements or descriptive observations. As the statements came from several people in the same organizations, it is not surprising that some of them overlap and a few contradict. For ease of interpretation they have been grouped into six categories:

1-0 Freedom and Local Autonomy
1-1 Permissiveness is allowed (at higher levels) in the choice of assignments, tasks, and projects.
1-2 Permission to do other work is generally allowed when time is available.
1-3 Personnel at higher levels may use available resources.
1-4 Bootlegging is possible.
1-5 Personnel usually choose work which is the most fun.

2.0 Goals, Support and Criteria
2-1 A high value is placed on ultimate goals, while a low value is placed on intermediate ones.
2-2 Schedules are more important than costs.

2-3 One is encouraged to raise his own money.
2-4 If one cannot raise money, he should support a project perceived as useful by authority.
2-5 If no useful project can be supported, one should show contributions to operations as an overhead expenditure.

3.0 Organizational Set for Development
3-1 Do not contract out your thinking.
3-2 Maintain technical direction "from cradle to grave."
3-3 Leave the resolution of conflicts to the latest possible time.
3-4 Design simple, operable and maintainable products.

4.0 World View
4-1 One has a major responsibility to the customer.
4-2 One should reference the greater environment.
4-3 One should always feel free to criticize external planning.
4-4 One should be willing to invest major resources in new areas.

5.0 Other
5-1 "Can do" attitude.
5-2 Creativity is good (in high levels).
5-3 Sensitivity to personnel human relations.

Systems Analysis, Simulation and Model Building

Extrapolating involves observing the current state and past performance of an organization and predicting its future course. The sets of statements just enunciated must be embodied in a model to test their interactions and to operationalize their content. In addition, the organizational, physical, and human structures of the organization should be modeled.

Before modeling, however, an analysis of the R and D society is necessary. The techniques developed by Hitch and his colleagues at RAND offer a useful structure for this purpose (Hitch and McKean, 1960). The major elements of all such analyses are as follows:

a) Objectives: What are the goals of the R and D laboratory?
b) Resources: What are the human, financial, physical and environmental resources of the R and D laboratory?
c) Models: What kind of structure, or theory or *modus operandi* characterizes their operation? (This will be structured at different levels and in a different manner, depending upon the analysis to be done).
d) Criteria: Who will evaluate the output and what are their standards?
e) Output: What is the product of the R and D society?

The descriptions of several research societies were reviewed by a panel of members of the R and D organizations. The descriptions, illustrating the terms in the systems analysis, are shown in Table I.

	OBJECTIVES	RESOURCES	CRITERIA	OUTPUT
Non-Profit	Survive with major contract, keep to prime mission, protect image	Decentralized Labs, high-level technology	Opinions of Government, services, Executive and Congressman	Paper, plans
Gov. Lab 1	Service a wide market, maximize empire	Labs, people, facilities, procurement capability	Budget, slots, major programs sold, technical reputation	Designs, procurement, papers
Univ.	Maximize reputation, satisfy teaching, maintain autonomy, maximize cash flow	Faculty, students, staff, facilities	Opinions of scientific communities and sources of money	Students and papers
Gov. Lab 2	Produce weapons, maintain status quo	Special facilities, reputation, experience	Users and Services, DOD	Weapons
Electronic-Aero Space Co.	Develop and produce systems and sub-systems for a profit	Facilities "know-how" large number of engineers	Sales and GOR (Gross Order Receipts)	Weapons, subsystems, and parts

Table I

Examples of R and D Societies in Systems Analysis Terms

SOME MODELS FOR ORGANIZATIONS

Most model building has centered around a theory, a viewpoint, or a structure, but all these models have been constructed for purposes other than studying a research society. They are essentially the crystallization of ideas, as opposed to the development of tools. It will be instructive to consider some of the models which have been proposed in the light of the aforementioned purposes. March, Simon and Guetzkow (pp. 36-47, 1958) summarize the early, bureaucratic models of organization of Merton, Selznick and Gouldner. The general concern of these models is to explain the control device affecting organizational behavior. They deal with gross aggregations such as "reward for control," "internatization of organizational goals by participants," or "levels of interpersonal tension." However, no matter how richly developed, penetrating or useful these concepts may be, they are far from adequate in describing complete, existing organizations and predicting their future behaviors.

An R and D society consists of entities (scientists, equipment, journals, etc.) and processes (invention, evaluation, report writing), and is therefore a highly complex organization. March, Simon and Guetzkow (1958) also develop many propositions and a series of sub-models which accent key considerations for a total system model. The concepts found in their sub-models, which emphasize set, perceived prestige of the group, and interaction, should be considered in designing an R and D Organization model, but because many of the necessary concepts and entities are not operationally defined nor their relationships quantified, no direct use of their models is possible. Cyert and March (1964) achieve success in modeling the decision-making parts of firms, but the model does not detail all the major organizational components at the individual level. The R and D society emphasizes activities and interactions which differ in their ultimate products. The product of industry and commerce is goods and services. The product of an R and D society is much more difficult to define.

Blau and Scott (pp. 40-43, 1962) consider many typologies of organizations: the dimensions of private vs. public; size; purpose; source of personnel (volunteers, employees or conscripts); sector (economic, political, religious or educational); people vs. object-directed charters (voluntary, military, philanthropic or corporations); and objective vs. means centered. These same authors choose a prime beneficiary viewpoint which classifies systems into mutual benefit association, business concerns, service organizations and commonweal organizations. None of the typologies, however, seem to assist in the classification and analysis of R and D societies, even though they do describe some important attributes. Biddle (p. 172, 1964) suggests that three types of conceptual systems are necessary to understand an organization: overt, cognitive and official. He further suggests that position, concepts of standards, and concepts of role are common to all three systems. A complex R and D organization may be studied by various indexes which fit several categories or which may have sub-units which fall into each category.

Collins and Guetzkow (p. 81, 1964) suggest that sources of organization problems may be generated either in the task environment or in the interpersonal environment; group behavior may thus be directed to either type of problem, with individual as well as group output yielding task environment and interpersonal rewards. Describing the environments of and within an R and D society is a difficult but necessary task.

Argyris (1965) develops an aggregate model, but he assumes technical competence, as he is more concerned with interpersonal behavior and attitudes, specifically with agression and competition between units. While the interpersonal aspects are important, the major differences between groups must also be accounted for.

Schein (1965), in his review of models in social psychology, identifies four major models and proposes a synthesis. The "Tavistock Model" is based on multiple channels of interaction between the environment and the organization (Schein, p. 90, 1965). Key elements include demands and constraints on raw materials, money, consumer preferences, expectations, values, norms of employees, task requirements, physical layout and equipment, all of which may be grouped into a technical system and a social system. The second model is based on Homan's work. This model considers physical, cultural and technological systems (Schein, p.91, 1965). The sentiments, activities and interactions developed outside of the system are called the "external system." The "internal system" corresponds with those sentiments, activities and interactions developed without relation to outside effects (e.g., developing an informal organization). According to Schein (p. 93, 1965), Likert adds the systems analysis concepts of a hierarchy of systems to the concept of key people who "link" organizations and environments. Lastly, Schein points out that the Kahn Overlapping-Role-Set Model adds the important concept of role sets (e.g., Role perceptions, role expectations, and role patterns are major factors in people's performance in organizations). Schein's (p.94, 1965) synthesis begins with the systems approach and views multiple, dynamic, interacting and hierarchical viewpoints. His synthesis is a good check mark for the student of the R and D society.

Roberts (1963), using Forrester's (1961) Industrial Dynamics model, explores aggregate factors, such as capabilities of management, experience delays, motivation, and availability. The use of the Industrial Dynamics simulation model restricts the user to a process (difference equation viewpoint) and prevents him from isolating individual units.

Boguslaw (p. 9, 1965) suggests four approaches to system design: the formalist approach, the heuristic approach, the operating unit approach, and the ad hoc approach. Viewing the R and D society as a system which we desire to model, we may consider which approaches may be used. Systems models might be explicitly used only in the formalistic approach, but the heuristic approach uses a model in which the heuristic operates, and an operating unit viewpoint needs models of operating units. The manager or designer who may use any of the wide variety of approaches mentioned will benefit from a model of a research society.

The "Levianthan" project (Rome and Rome, 1962) has studied an artificial organization with normal and social structures, where the "productive agents" are given an organizational assignment and a skill description. Many of these concepts will be useful in simulating an R and D organization. The use of computer simulation where the organization has been mapped is very significant, because it demonstrates the feasibility of modeling individuals in an organization setting (Gullahorn and Gullahorn, 1965). In the studies of role-conflict, use of the "Homunculus" model incorporated many human characteristics, showing the level of detail in individual interactions, but not including the dynamics of organizational interaction. Orcutt et al (p. 222, 1961) asserts that micro-analysis is the proper level of study for socio-economic systems and discusses the problems, dangers and disadvantages of aggregating phenomena. These concepts should be kept in mind for each model builder. His position is directly applicable to the problem of modeling an R and D society. The opportunity to develop such models will not only require major efforts in model building, but will also require much empirical study. Model building and data collecting go hand in hand and should alternate until criteria are achieved.

None of the models discussed have had the objective nor seem to have the capability of simulating an R and D organization at the level of detail needed to explore at the capability or skill level. The concepts which have been formulated, the theories which have been considered and direct experience with R and D societies suggest several propositions. The explicit formulation of these statements and their logical support may be achieved in a model of an R and D society. If the propositions pass a test of plausibility, we may test them empirically, using the model format, if appropriate to the desired test. The propositions are as follows:

Proposition 1: Required levels and variety of skills decrease as a function of project phase.

Proposition 2: Requiring low level skill performance from high level people is easy. The general consequence is losing the high skill personnel.

Proposition 3: The pattern of resources required in an R and D society depends on phases of projects. Therefore, an organization with one major project will require major changes in its resources structure. An organization with many major projects can balance resources and keep a constant structure.

Proposition 4: Capability may be achieved by "essential decentralization" (Shelly,1965) with competition and lack of constraints on growth or "centralization," which creates differentials and focus activities, eliminating competition.

Sub-Proposition: Permissive decentralization with no competition leads to a loss of capability.

Proposition 5: Major descriptions and dislocations of the skill structure are eventually required if the organization as a whole is to survive. If the rate is too high it will never achieve a capability; if too slow it will not develop new, needed capabilities.

Proposition 6: A minimal distribution and quality of personnel is needed to survive. Some of the personnel required will not stay if a minimum capability does not exist.

THREE MODELS FOR A RESEARCH SOCIETY

Different models serve different purposes. In this section three classes of models which seem to be necessary for simulating a research society will be presented. The ensuing discussions will explain why three types of models are required, how they may be used, how they are interrelated, and how system simulation principles are classified and evaluated. Several different but related models are required to describe a research society because of the complex relationship between its elements in an environment, including those relationships peculiar to the decision-making units and other elements within the required structure. Each model was chosen for its special dimension or sensitivity to the study of research societies, either in terms of data collection, data analysis or as a source of design principles.

The three models to be discussed are as follows:

a) The interface (Black Box) Model. This model specifies all the inputs to and outputs from a system in great detail without considering the structure of the system's elements. The electrical engineers are concerned mainly with determining one equation that relates inputs to outputs (transfer function for this type of model).
b) The Functional System Flow (FSF) Model. This model emphasizes the relationships between the parts or elements of a system.
c) The Goal-Seeking (ml-mg) Model[1]. This model specifies a series of objectives or goals of the system in its description.

Because each of the three models emphasizes a different important characteristic of a system: inputs/outputs (I/O), objectives, and structural relationships, all three have important uses.

Models

Models may serve as a frame of reference for descriptions and analyses of a research society. The models establish a structure for data gathering, hypothesis generation and prediction of organizational behavior. Useful models should be:

1. Operational - allowing the user to measure all concepts, entities and attributes
2. Realistic - embodying the key features of that which is being modeled in a manner that is recognizable and operationally definable
3. Modular - allowing the user to abstract at different levels the important elements
4. Predictive - allowing the user to predict the behavior of the real system under a moderately changed or completely new situation
5. Satisfiable - allowing the user to manipulate the elements of the model in order to achieve a satisfactory function performance

A successful model must include all the key characteristics of a system

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[1] I am indebted to M. O. Mesarovic for his assistance in formulating many of these ideas.

and its elements so that the major functional characteristics of the real-world system which it is trying to simulate are represented.

The model must operate at two levels:

1. Organization level, showing the structure of the individual decision-making units (people) as they relate to each other
2. Decision-making unit, showing the relationship of the decision maker to its immediate environment (i.e., inputs, outputs, relation to next lower level, relation to next higher level)

Principles

To describe a research society, a set of disciplined principles is necessary. System principles may be derived empirically. Observation of actual operations, or experimentation (wherein an attempt is made to replicate the real-world) are excellent sources. System principles may also be deduced from theory. For the proposed simulation, many principles and hypotheses must be gathered; however, those which appear to be testable should be preferred.

System principles may be classified as:

1. Existent: These are principles which express the necessity that relationships or elements must exist in order for the organization to perform certain missions or to meet its objectives (e. g., a test range).
2. Structural: These are principles which express the requirement that within the organization certain structural relationships must exist (e. g., parallel laboratories).
3. State: These are principles which describe the way in which the state of the organizations varies under different conditions (e. g., effect of different size budgets).
4. Parametric: These are principles which provide the range of values (useful, dangerous, etc.) for the parameters which are recommended for the structure (e. g., maximum size for each department).

Each system principle must be evaluated in terms of four criteria:

1. Broad: usable for the required range of problems
2. Reliable: work upon successive repetition
3. Valid: apply to the main mission of the organization
4. Economical: studying the principle should not cost more than operating the real system.

The Interface (Black Box) Model

The Black Box Model (Goode and Machol, 1957), stemming from the transfer function approach routinely used for many simple problems, is generally inadequate to describe a research society or its decision makers. On the other hand, the insistence upon a clear specification of all factors affecting the systems (inputs, e. g., requirements from the operational units) and all other areas affected (outputs, e. g., specifications for parts) is important in gathering data and describing complex systems. Further, the description requires that an attempt be made to translate all external factors, including the environment, to a common base. The representation of what occurs within the system, in formal terms, is called the transfer function. Transfer functions are not normally derivable and manipulable in real and complex systems. The complexity of the embedding environment has been illustrated for the case of a large, decentralized corporation (Rubenstein and Radnor, 1964).

The Functional System Flow (FSF) Model

A functional system flow (FSF) model traces the flow of a specified relationship from the input to the output of a system. The relationship may be information flow, orders flow, power flow, sequence flow, etc. (e. g., Forrester, 1961). The elements of an FSF model are as follows:

a) The inputs and outputs, as defined in the Black Box model, relevant to the particular flow being modeled. Generally, the FSF model will always have less emphasis on I/O's than the interface model.
b) Entities, which are defined as those system elements which transform or modify the flow (also called nodes), and items that flow (e. g., scientist, machine).
c) Attributes, which are the characteristics of entities (e. g., skills of the scientist, probability of a piece of experimental apparatus breaking down).
d) The direction of flow, which establishes the relationships among the entities or the structure (also called links) (e. g., routing of a sample through the chemistry lab).

A functional system flow model extracts some system characteristics which in many cases are judged to be essential or central. The description then proceeds to trace through the system flow and identify the operators of interest. Generally speaking, information flow or decision flow is the basis of the analysis of information systems and is the approach of the systems engineer who traces functional flow throughout a system. This technique can describe virtually any complex system and is limited only by the time and effort needed. Many techniques, like computer programming and PERT, use the FSF model as their basis.

A Black Box analysis of an R and D lab has much to do before the next step may be taken. On the other hand, at the FSF level, Figure 3 details the information environment of the project engineer.[1]

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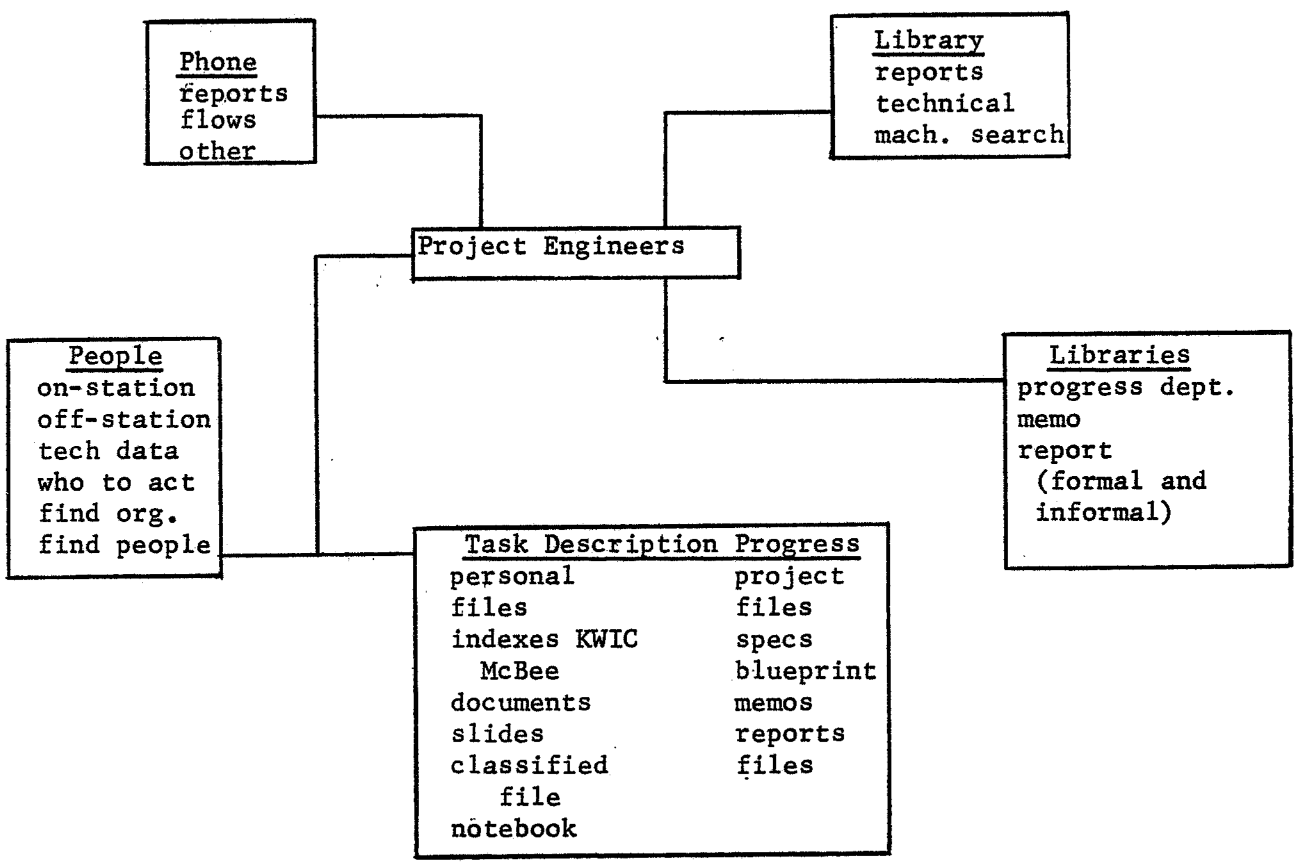
[1]This data was collected from discussions with government R and D lab personnel.


Phone
reports
flows
other
Library
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technical
mach. search
Project Engineers
People
on-station
off-station
tech data
who to act
find org.
find people
Libraries
progress dept.
memo
report
(formal and
informal)
Task Description
personal
files
indexes KWIC
McBee
documents
slides
classified
file
notebook
Progress
project
files
specs
blueprint
memos
reports
files

FIGURE 3

A series of interviews with Project Engineers, as illustrated, yields the following incidents. Data like this (or their possibility) must be incorporated into the model.

INCIDENTS

	Requirement	Outcome
good incidents	letter	coordinated very quickly
	data about a contractor	called friend and found information right away
	search for bid specifications	retrieved all relevant items
	requested data	on boss's desk, just received in mail
	looked for book	found good data
	science data	found data in one call and four hours
	data	requested data, got names and phones from people who could furnish information
bad incidents	request for film	could not find
	purchase of lab equipment	lack of information led to delay in buying
	attend meeting	no information on it - waste of time
	used abstract	report, in fact, was not good
	reference	could not find
	scheduling	lack of information
	look for report	boss had it
	look for form	cannot find

One small portion of an R and D society is the personnel recruitment and turnover sub-system. A series of changing job demands will ultimately change the composition of an organization. An FSF model showing this process is shown in Figure 4. This same model is presented in terms of a SIMSCRIPT formulation in the latter portion of this discussion. The model shows people (who have skills and experience) being processed by personnel. The people required, as specified by the laboratories, are based on job requirements and existing personnel. The number and type of existing personnel are affected by the separation and transfers which occur. The number of separations and transfers depends upon the job demands and personnel environment.

The Goal-Seeking (ml-mg) Model

To understand the difference between the previous models, which are "causal," and the new model to be introduced, which is "goal-seeking," one must define several terms. A goal-seeking system is one which must penetrate within the system boundaries in order to establish purposive, technological or goal-seeking elements (e. g., a scientist wants knowledge). A causal system consists of observing causes and effects, and deriving a mechanistic description of the transformation. Causal systems cannot change their structure. Goal-seeking systems may change their structure. Structural changes include organizations of parts, criteria, inputs received, utilities and other basic characteristics. Virtually all systems may be viewed either way, or parts of a system may be viewed in different manners. A common practice in the goal-seeking approach is to allocate certain functions to a causal part of the system. A goal-seeking system may be classified by the complexity of the hierarchy of the goal-seeking elements, as shown in Figure 5. The single level, i.e., single goals seeking model, is adequate for single objectives, but a multi-level (ml) multi-goal(mg) model is needed to describe actual organizational behavior.

Generally speaking, one may describe the causal part of a system by the function $Y = Q\ (X,S,P)$.

$\underline{Y}$ is the output of the system.
$\underline{X}$ is the input of the system (including the environment).
$\underline{Q}$ is the structure of the system (only a self-organizing system may change its own structure, and no algorithms exist to optimize structure).
$\underline{S}$ is the state of the system (this characteristic reflects the accumulated changes of the system, such as capability, memory and experience).
$\underline{P}$ is the parametric set of the system (which establishes the quantitative characteristics of the structure (Q), which can be optimized).

The level of ignorance regarding the five variables discussed allows one to classify systems as:

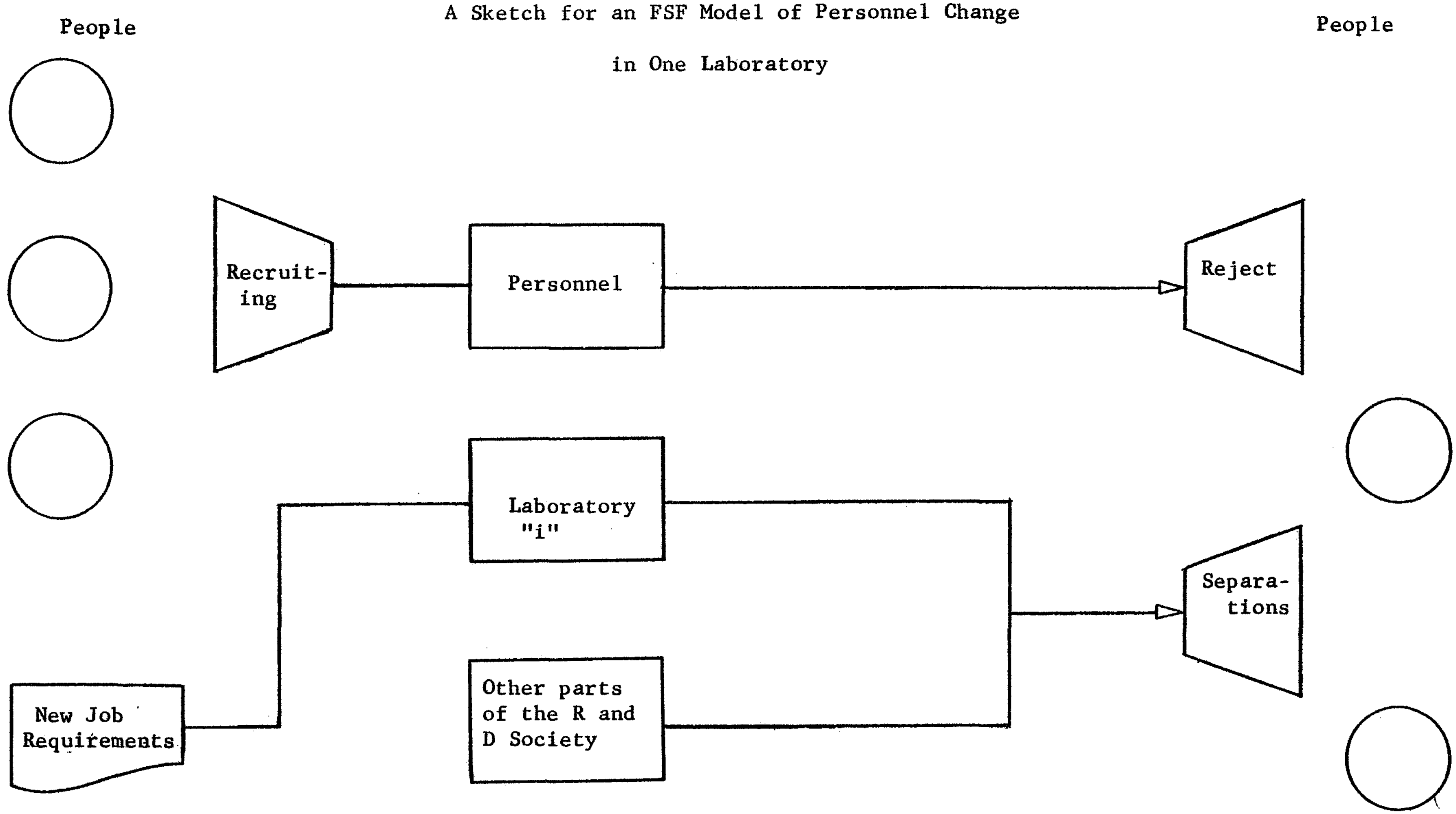
1) Closed: all elements known.
2) Open: not all elements known but the set to which the elements belong is known ($X \epsilon \underset{\Omega}{x}$).
3) No System: not even the class of elements is known.

For the purposes of studying research societies, one needs a model which is open, in order to deal with an uncertain environment. For purposes of analysis, one may wish to put the system into certain restricted environments to allow the analysis to proceed properly on a closed-system basis.

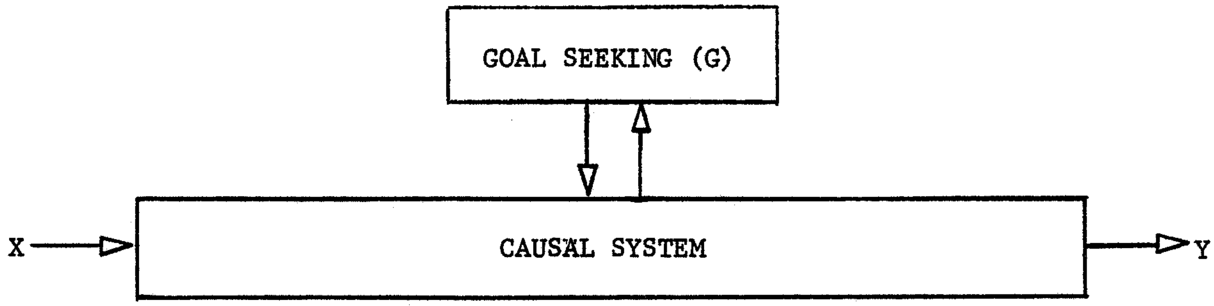
FIGURE 4

A Sketch for an FSF Model of Personnel Change

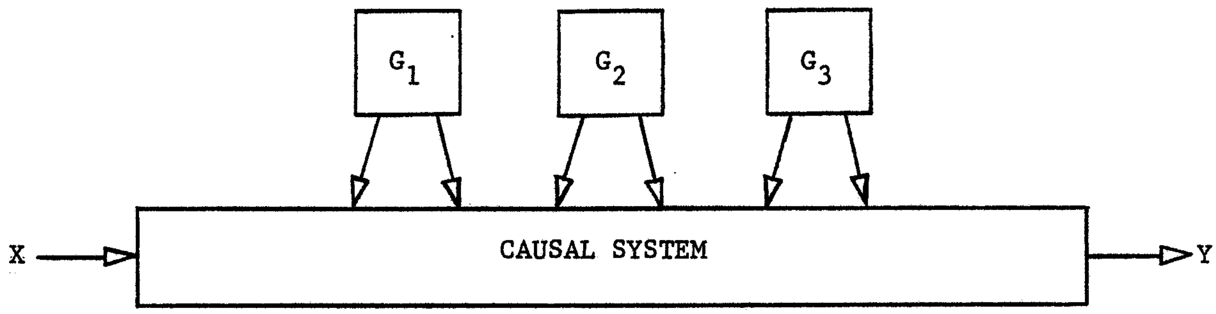
in One Laboratory



A single level - single goal(1l - 1g) model



A single level - multi goal (1l - mg) model



A multi level - multi goal (ml - mg) model

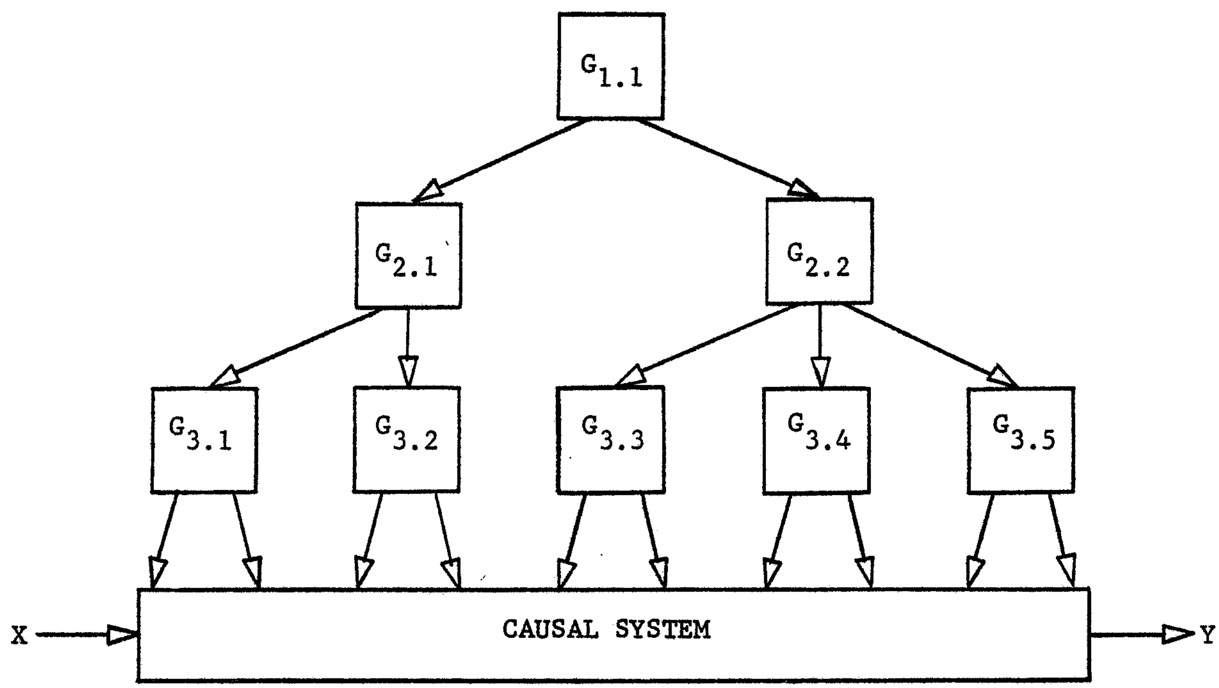


Figure 5: A Classification of Goal-Seeking Systems

To develop a complete, expanded model, other major elements must be defined:

- $\underline{x}$ is the description of all possible inputs to the system.
- $\underline{m}$ is a specific decision (or order generally directed to the causal system).
- $\underline{\Omega m}$ is the set of possible or allowed decisions(m).
- $\underline{\Omega a}$ is the set of allowed ratio of generalization to prediction in the adaptor.
- $\underline{e}$ is the error found in the system performance.
- $\underline{p}$ is the strategy passed on.
- $\underline{q}$ are the utilities or values of each function or entity.
- $\underline{\alpha}$ is the tolerance or criteria for acceptable performance.

Having defined the key terms, one can now consider a reasonably complex model.

A self-organizer model is a complete decision-maker in all its possible complexity. A simpler configuration exists when the decision set (Ω_m) required is simpler, the uncertainty set has been changed (reduced), the system tolerance increased, and the utility function relaxed. The simplified models contain fewer functions. Mesarovic discusses this model in detail elsewhere (Mesarovic, Sanders, Sprague, 1964).

The self-organizer is the first level, goal-seeking unit. It is concerned with determining the utilities (q), the decision sets (Ω_m), the adaptor configuration set (Ω_a) and the level of satisfaction (a). The values or worth (q) of every functional requirement must be prepared. A block diagram of the model in Figure 6 shows the adaptor-configuration set (Ω_a), which establishes predictors and/or generalizations which will be used; Ω_m, is the decision set (i.e., establishes whether the possible decisions will be allowed out of the system); and α, which is the level of satisfaction or level of performance which will satisfy the system performance values.

The second level unit is the adaptor which consists of two elements, a predictor and a generalizer. The function of the adaptor is to improve the ability of the system to deal with uncertainty. Both the predictor and generalizer are concerned with establishment of the uncertainty set (Ω_x)(i.e., the set of information which the system might be receiving at some future time). Extrapolations on the basis of a given algorithm from present and recent past data are normally called predictions, as opposed to generalization, which is an examination of the functional characteristics of a set of data in order to establish the basic relation which will generate future data.

The third level unit, the decision maker, is the tactician, who directly controls the causal system. The decision maker consists of three parts:

1. An evaluator, which, given the utilities (q) received from the self-organizer, the decisions made by the decision maker, and the performance generated by the system, gives information to the decision maker on how well it is doing.
2. The decision maker proper, which is concerned with establishing the strategies to be used in pursuing the goal as specified by the decision set, level of satisfaction, the utilities, and the uncertainty set.

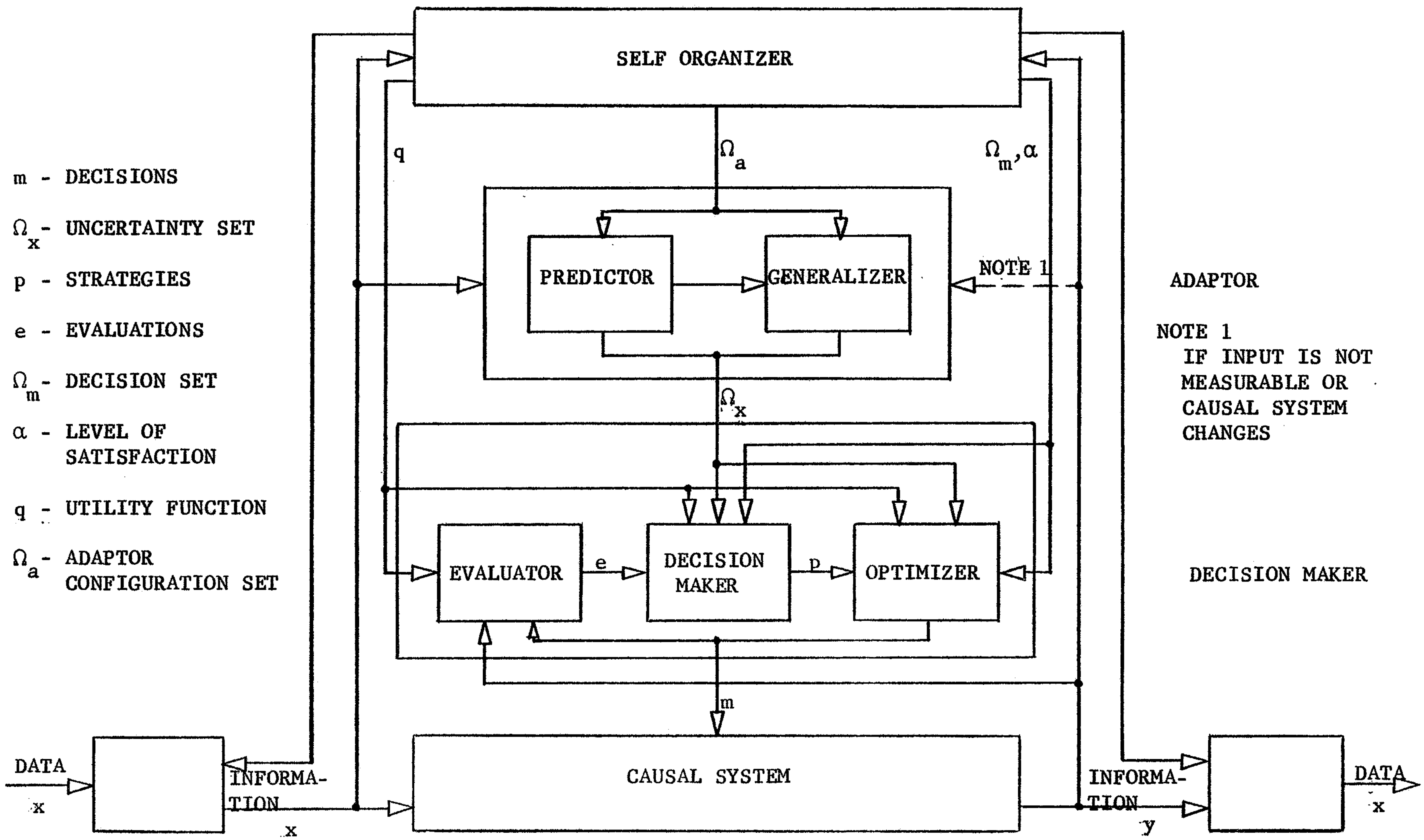


FIGURE 6

The Fully Expanded Goal-Seeking Decision Maker

3. The optimizer, which is a mathematical operator which carries out optimization functions to achieve the utilities (q) as closely as specified by $\underline{a}$ and the decision maker.

The causal system consists of working elements which actually operate on the information that comes out as the input.

Two transformations occur in the input and the output. One is data transformation; the other is transformation from information to data. Both transformations are classified as transducers, which are external to the self-organizing system, but in many cases will be related to them. This general functional description can describe virtually any decision maker alone or as part of an ml-mg system.

The ml-mg analysis will indicate whether certain goals, relationships, and objectives which are necessary have been included or omitted. The FSF model will point out whether the system designed is sensible within the state-of-the-art and whether the relationships which exist are possible from a technological viewpoint. The Black Box approach states the initial problem and emphasizes the environment in which the system operates.

The importance and rate of development of models has been increasing in several parallel directions. The Interface (Black Box) Model, the Functional System Flow (FSF) Model, and the Goal-Seeking (multi-level multi-goal) Model can make major contributions to the task on hand. In a manner analogous to a problem in physics, where two viewpoints are necessary to discuss the nature of light, where wave theory explains some aspects and particle theory others, these three models seem helpful in describing the complex phenomena under consideration. The Interface Model stems from a practical engineering approach. The FSF Model is one of the techniques for analysis and synthesis of command and control systems. The goal-seeking approach attempts to use a purposive or teleological consideration as a major simplifier of the description, and allows one to describe very complex behaviors with a number of reasonably well-defined elements. For the purpose of describing research societies, R and D laboratories, and other complex adaptive systems the ml-mg model seems to be an appropriate addition, but at this level many of the other models could be used also.

3.0 Reasons for Simulating a Research and Development Society

It has been suggested that "Although our eventual goal is the statement of laboratory management problems in a mathematical or computer language, it appears that this goal is currently better served by adopting a framework which excites the imagination, lets new associations be formed, calls upon intuitive insights and avoids administrative clichés rather than by adopting an exclusive insistence upon rigor and exactness before we have a good indication as to what avenues might justify the substantial efforts required to achieve exactness." (Shelly, 1965)

The inertia of exactness of mathematical models and the severe restrictions imposed by them do rule out mathematical models for many solutions. The use of mathematical and simulation models is imperative and not restrictive if they are used as guidelines and objectives rather than as unique methods of solutions. A discussion of simulation and models in general is in order.

3.1 Reasons for Simulation

Simulation serves as a valuable adjunct to experimentation and theory building. The following are some of the reasons for using simulation:

3.1.1 Detailing Predicted Phenomena	One cannot closely observe some phenomena, such as rocket motor failures, interstellar interaction, or details of the future growth of an R and D society.
3.1.2 Creating a Model to Explain the Phenomena	Simulation may be used when it is not possible to reduce the phenomena to a theory. A model of an R and D lab may be built even though it cannot be fully described in closed mathematical form or in terms of any existing theory.
3.1.3 Predicting Observable Phenomena from the Theory or Model	It is sometimes impossible to go directly from a theory or model to operational predictions. The simulation allows one to "reduce it to practice." For example, the prediction of department size depends upon the skills of the personnel who are required to meet the objectives.of the department. Certain skills, such as those of an experimental physicist, may require a larger supporting staff than those of a test engineer. Thus a shift in skill composition from experimental physicist to test engineer may greatly alter department size.
3.1.4 Performing Experiments to Test the Theory	Some experiments, such as war or interplanetary travel or several alternative changes to an R and D society, cannot be conducted in actuality. A simulation allows one to try.

3.1.2 Simulation may be used to assist the management scientist, in new areas, as a basis for orientation and organization. He may use it to:

3.1.2.1 develop a description language
3.1.2.2 gain familiarity with the phenomena
3.1.2.3 determine the data required
3.1.2.4 determine which variables are significant (sensitive).

3.1.3 There are several pragmatic reasons for simulating:

3.1.3.1 It is a good training device for the practitioner and user.
3.1.3.2 It is sometimes cheaper to simulate than to pilot plants or to experiment.
3.1.3.3 It may be used to check analytic solutions.
3.1.3.4 It may be used to demonstrate the feasibility and promise of projects in order to "sell them."

3.1.3.5 It can predict trouble areas.
3.1.3.6 It can provide control for time processes; for example, speeding up a growth process, or slowing down atomic phenomena.

Many early examples of simulation may be reviewed in Morgenthaler (1961).

3.2 The Basic Structure of Simulation

All simulations have a set of common elements, concepts, operations, and requirements. A series of definitions will be given to establish a basis for further analysis.

3.2.1 Primitives of Simulation languages

Every simulation language must enable the analyst to cover several major elements:

3.2.1.1 Entity:

3.2.1.1.1 Recipient of behavior or action, such as a transaction in the GPSS (1963) language or likeness to a noun in English (e.g., an idea, or a project, or a person).
3.2.1.1.2 That which acts, like a block in the GPSS language or likeness to a verb in English (e.g., a machine tool (produces), a weapon (destroys), or a person (performs).
3.2.1.1.3 Attribute, the permanent or temporary characteristics of an entity (e.g., the time a project will take or its cost, the skills of a scientist).

3.2.1.2 Structure: A series of rules which describe the allowed directions of movement of entities or the relationships between the parts, e.g., the organization of a laboratory (formal-informal, decision studies, procedural, etc.).

3.2.1.3 Clock: A clock is needed to pace the simulation and to coordinate the activities.

3.2.1.4 Flow: (e.g., something moves or changes in all processes: chemicals, R and D societies, ideas, people). Flow, sequence or ordering specifies the successive movement in <u>time</u> or space of entities with which other entities interact; the defined elements allow one to "privately" simulate a system. Every system may be simulated with entities, structure, a clock, and flow.

3.2.2 Meta Primitives

In addition to the primitives needed to build a simulation, further features are necessary to allow them to be public. A "private" structure which can neither be maniupulated nor observed is useless.

3.2.2.1 Inputs

A simulation must be exercised to be useful. One must be able to set up situation, present data, organize circumstances to test policies, structures, or whatever is appropriate. In studying a research society one may wish to vary the probabilities of recruiting certain skills, duplicating the fiscal cycles for the last 5 years or reorganizing the laboratory. The simulation requires access to changing the system, the environment or both.

3.2.2.2 Activities Records

A simulation yields much more than the final state of the system. One must be able easily and selectively to record and display the behavior of entities and their attributes. In some cases all the history should be recorded; in other cases, only parts (e.g., one might wish to record the mean and range or personnel in each department every year during the life of the laboratory).

3.3 Factors Affecting the Utility of a Simulation Language

3.3.1 The System Concepts

3.3.1.1 The point at which a specific configuration is chosen, the temporal characteristics of entities, and the continuity of time on mathematical power are key considerations in evaluating a language. The level at which entities are developed affects the flexibility of the simulation. In a "simulator defined system" one deals with the specific entities designed (e.g., the programmer builds it to describe a specific R and D laboratory). In a "user defined system," the user describes the program. (He sets up the configuration of the lab he wants to study.) In systems defined after pre-processing, even more flexibility is achieved, with the highest level occurring in systems when changes occur during running.

3.3.1.2 The permissible characteristics of entities and their attributes, whether temporary or permanent, may greatly affect efficiency.

3.3.1.3 The concept of time used is important. Continuous time allows for simultaneous processing of activities, but may waste much time during "uninteresting periods." Discrete time moves from one significant event to another, but its efficiency leads towards the loss of the detail which was not originally planned.

3.3.1.4 The range and power of mathematical and logical routines are important variables in determining system usefulness.

3.4 Ease of Use for Simulation

Several characteristics of simulation will affect their ease of use. Simulating an R and D society requires the minimization of as many difficulties as possible in the use of the language, for the complexity is close to overwhelming. Different languages offer features which are either unique or which differ in power. A review of these features is important, so that one can consider whether simulation is appropriate and, if so, what language should be chosen.

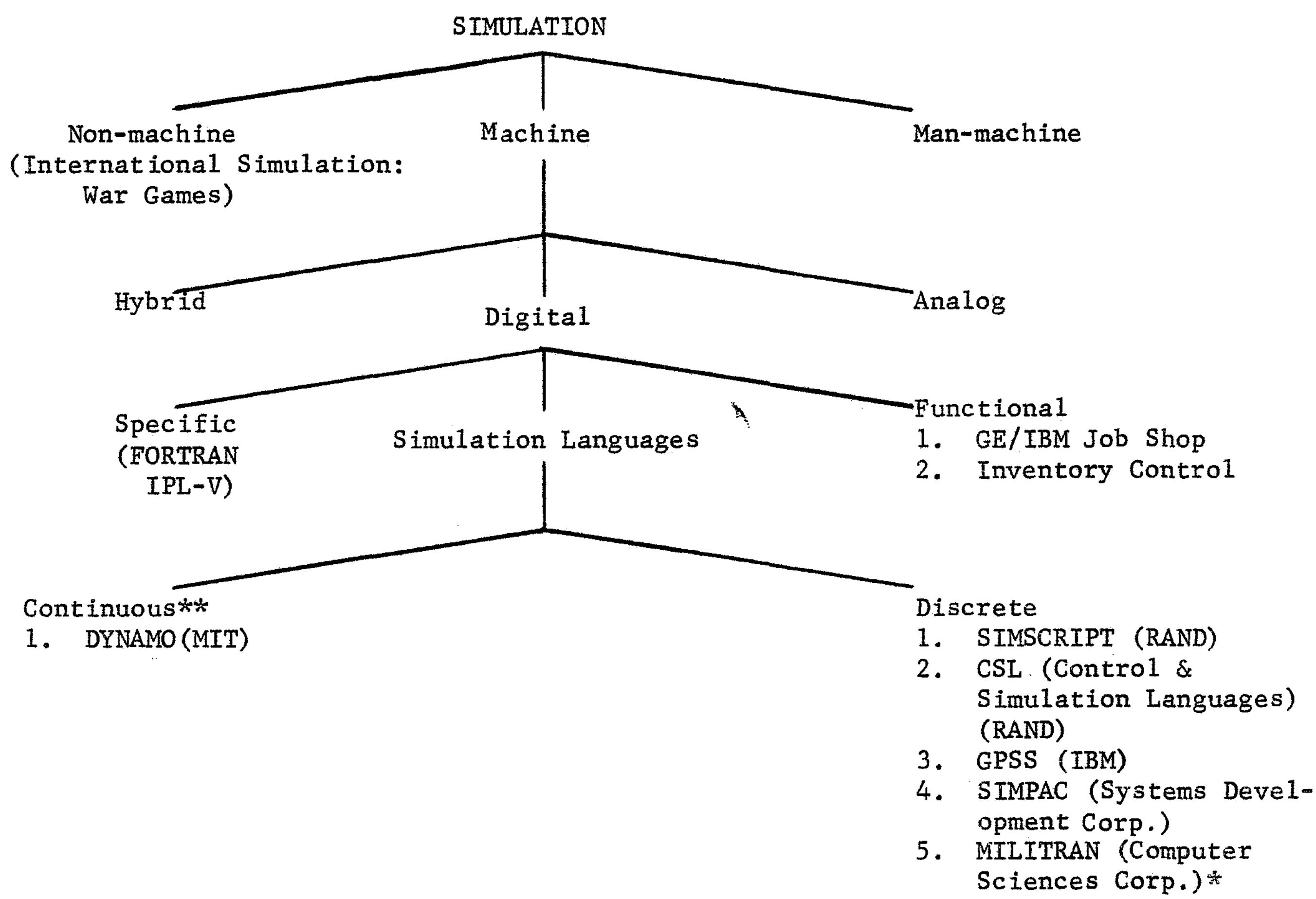
Features to be considered, variation in terms of the structure of the simulation to be programmed:

3.4.1 Modularity (the ability to combine parts of the program written by various people or written at different times)
3.4.2 Initialization (the structure that allows one to specify the initial conditions in detail, instead of having to "warm it up")
3.4.3 Size limitations of problems, variables, parameters, etc., is critical. This may be computer or a language limitation.
3.4.4 Variable names for parameters, variables, etc., are helpful in using and explaining the language.
3.4.5 Amount of storage space used in compiling affects the length of the program used or the ease of building it.
3.4.6 Packing or words (In large programs, allowing the use of parts of a word is very important for list processing and efficient use of the computer.)
3.4.7 Dimension-free arrays (Not having to save space which is not in use is a great saving.)
3.4.8 Temporary and permanent entities. (Not having to keep used-up entities is very helpful.)
3.4.9 Form. (The ability to specify the output form, the path of the entities and types of summary statistics is very important.)
3.4.10 Form. (The ability to punch cards and print tapes of the history, analysis, and state of the system is very important.)

IV. A TAXONOMY OF SIMULATION LANGUAGES

Many types of simulations exist. A taxonomy for simulation will be helpful in focusing on the type of languages which should be used by the student of R and D. A series of steps proceeds from the man-machine dichotomy through the analog-digital-hybrid continuum to the types of languages.

The family tree of simulation:



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*Newly Announced.

**Continuous System: one in which every basic variable is continuous and possesses a first derivative with respect to time. In other words, the state of the system is given by the levels of these continuous variables at any part in time, and one may not conceive of any discrete changes in this state.

While many simulation languages have been developed, the ones listed under the heading of Simulation Languages are the best known and most representative of those used today and are of special interest to the simulation of R and D societies. Each involves a "World View" which provides the user with a way of thinking about his system. All except DYNAMO are basically discrete simulation languages. DYNAMO, the only continuous simulation language, is closed loop, patterned as an information feedback system. Its author used and recommends it for detailed comparisons of language.

SIMSCRIPT and CSL are the most flexible (more "set" oriented) languages. SIMSCRIPT is available on a variety of machines, but CSL is virtually unavailable to most users. GPSS, which is available on IBM 709, 7090, provides an easy conceptual framework and is more powerful on problems within its range. SIMPAC, while highly specialized, allows more general concepts than GPSS. DYNAMO does not possess the descriptive capabilities of the others, but has extensive capacity for continuous feedback systems. It is very accessible and if one can formulate the problem as difference equations, he should probably use this language.

Other variables should also be considered in these simulation languages. In regard to storage and retrieval of data, SIMPAC is the most flexible, followed by SIMSCRIPT. GPSS II, with its fixed parameters, is restricted but simple to use. In consideration of arithmetic operations, SIMSCRIPT and CSL, which use FORTRAN, are the most powerful. GPSS uses variable statements and allows for computation. SIMPAC uses symbolic coding. DYNAMO has a fixed set of equation types and may be confining. In regard to Sort Operations, SIMSCRIPT, CSL and SIMPAC are all flexible, while GPSS utilizes blocking techniques.

While all these languages have arithmetic testing, each is strong in different areas. Only GPSS has direct delay until a successful test (gate) is cleared. Only DYNAMO revises the values of variables.

If we rank by ease of use for simulation:

1. DYNAMO is the easiest to use if the dynamics of the system are known.
2. GPSS is the most highly structured.
3. SIMSCRIPT and CSL are most difficult to use, although more flexible.

SIMSCRIPT has special commands for developing and computing time.

CSL has similar commands, plus the ability to maintain histograms (distributions of transit times). GPSS also maintains queueing and equipment utilization data and computes summary statistics. SIMPAC can produce output tape which can be subsequently analyzed by programming. DYNAMO does not compute statistics.

DYNAMO is the most efficient language because it is the fastest, while SIMSCRIPT is very efficient in memory utilization. GPSS allows modification on each run, but CSL and SIMPAC must be recompiled to change the structure. SIMSCRIPT can make many changes through initialization; DYNAMO permits limited changes at each run. DYNAMO, however, is very hard to debug. GPSS is very good to debug, because it gives a strongly detailed error output in source language. While SIMSCRIPT and CSL require the user to work with FORTRAN programs for debugging, SIMPAC's macro-construction requires the user to work the difficult SCAT language. The Simulation of an R and D society would probably be best carried out in SIMSCRIPT or GPSS III. Before deciding to do so the check list contained in

Appendix A should be applied.

From the discussion of the level and detail of the simulation of the three models of an R and D society, the suggested level is that of people as entities or blocks, and skills as parameters or attributes. Facilities, jobs, money, time, outputs (reports, specifications), control and information flows should be worked out and the immediate environment added. The size and complexity of the required program will tax an IBM 7094 and should be handled on a large IBM 360.

The complexity of the problem of building a model of an R and D organization is matched by the magnitude of the data problem. The model of the R and D society may serve as a model for the data structure, and an information system to process and service the data requirements must be developed for the simulation project. Careful structuring of data to serve as the basis for the simulation of a Black Box or FSF model is critical. Current advances in information retrieval should be applied to insure efficiency and power to the system.

McGrath (1964) suggests that computer simulation is a third stage of a five stage process or programmed research, and that its special utility is in the elaboration and refinement of theoretical models. The approach suggested here is that a simulation has a role in each stage. It does not replace, but complements field studies, experimental simulations and laboratory experiments.

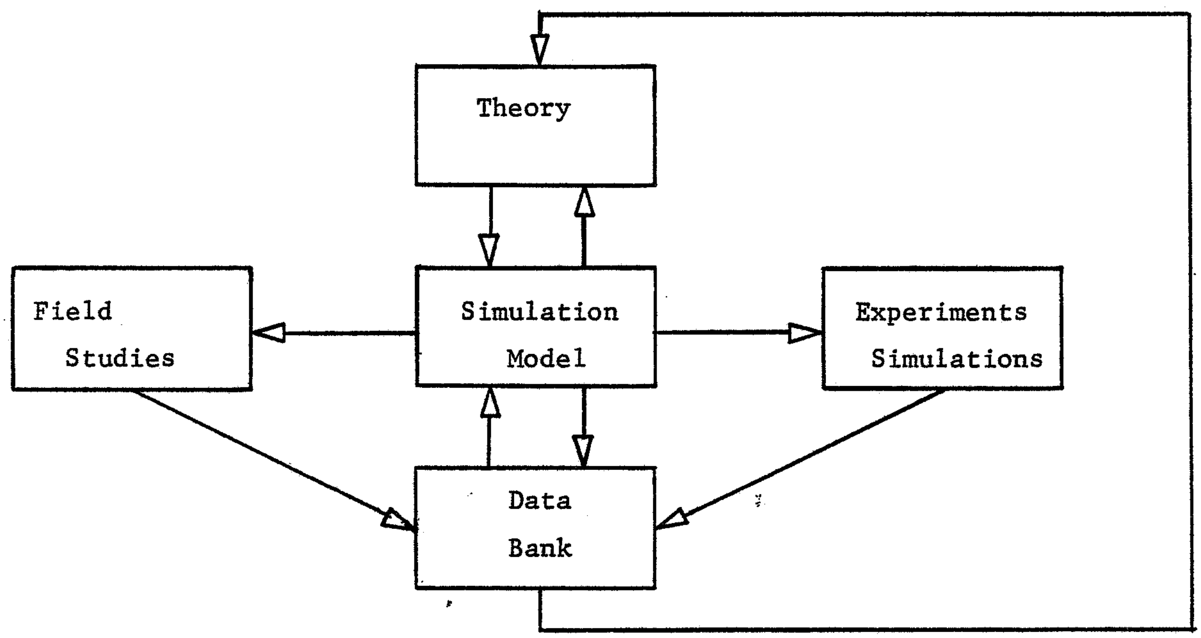
Using McGrath's stages, one can suggest how simulation may be appropriately carried out at each level:

TABLE 2

Stage (McGrath, 1964)	Use of Computer Simulation
1. Exploratory studies when little is known of phenomena	Develops and tests a logical language for the description and measurement of phenomena
2. Follow-up studies for precise testing of hypothesis	Use to screen hypothesis, check design, plan analysis
3. Elaboration and refinement of theoretical models	Detailing and testing of many alternatives
4. Validation of theoretical models in limited situation	Uses experimental data to validate theory
5. Cross-validation of theory in real life situation	The model is used as the predictor and tested; if correct, the theory is supported.

A new diagram is suggested to illustrate the role of the simulation model:

FIGURE 7



Three levels of modeling may be carried out. The first level is that of the researcher. One may aggregate the functions of the environment and the organizations, concentrating on the behavioral changes and the dynamics of the individual (e.g., Feldman cognative simulator (1963)). At a higher level one may simplify the model of individuals to the skill level and have several parallel organizations where individuals are exchanged, skills added or modified (e.g., Rome's system (1962) and Orcutt's model (1961) of the family) and facilities manipulated. The third level will concentrate on the interactions of the organization with the national economy, science and technology, education, industry, defense and the world situation (e.g., the TEMPER model at the Joint Chiefs' War Gaming Agency or Guetzkow's Inter-Nation Simulation (1962)). A first step in carrying out the proposed simulation has been to formalize some of the manpower characteristics in a SIMSCRIPT program. Such a program shows our fact ignorance and points the way to detailed data gathering.

In any approach to modeling the R and D organization, one must be aware of the complexity of the problem, in terms of its changing characteristics. The decision to simulate must be a result of the considerations necessary for simulating, in terms of people and skills. The three levels of modeling, together with computer simulation, will, if properly and cautiously used, be of benefit to the user.

A demonstration of the level of detail required to simulate the function of and terms for a SIMSCRIPT program are presented in the following Appendix. The detail which must be gathered before a simulation is carried out may be defined through this process.

APPENDIX A

DEFINITION OF VARIABLES

CHNG - a set containing men who have left the system until the end of a report period when they are printed out and destroyed. Members are MAN. SCHNG is an attribute of MAN which describes his successor in CHNG. FCHNG and LCHNG are system variables which denote the first and last MAN in CHNG. The set is FIFO. NCHNG is the number in CHNG.

ETAP - a system variable containing the elapsed time between endogenous events of the type APPL. This is the frequency with which NAPP men will apply for a job, in days.

ETHR - a system variable containing the elapsed time between endogenous events of the type HIRE. This is the frequency with which the set POOL will be checked for qualified applicants, in days. (A permanent system attribute).

ETQT - a permanent system attribute containing the elapsed time between endogenous events of the type QUIT. This is the frequency with which a MAN may quit the group GRP, in days. His probability of quitting is PBQ.

ETRT - a permanent system attribute containing the elapsed time between endogenous events of the type REPT. This is the frequency with which the report generator will be called, in days.

GPSK - a permanent entity standing for the skills which will be found in the group (or in each MAN). Thus NGPSK is a system-generated variable which is the number of GPSK's.

GRP - a set containing members MAN. It describes the research group. NGRP contains the number of entities MAN in GRP. SGRP and PGRP are attributes of each MSN in GRP, describing his successor and predecessor. FGRP and LGRP are system attributes describing the first and last MAN in GRP. GRP is a ranked set, using the attribute of MAN, ID as the ranking parameter, with lowest values first.

RIEV - a permanent attribute of GPSK describing the shortage (in number of men) of highly skilled persons (level 8 to 10) in the group GRP (or HIGN minus HIGA).

HIGA - a permanent attribute of GPSK describing the number of highly skilled (level 8 to 10) persons in GRP for each GPSK.

HIGN - a permanent attribute of GPSK describing the number of highly skilled (level 8 to 10) persons needed in the group for each skill GPSK.

ID - a temporary attribute of the entity MAN describing his identification number in the system.

<u>LEVL</u> - a temporary attribute of the entity SKIL, a level of proficiency for that skill. The values are integers between 1 and 10.

<u>LOWA</u> - a permanent attribute of GPSK describing the number of low-skilled (level 1 to 3) persons in the GRP for each GPSK.

<u>LOWN</u> - a permanent attribute of GPSK describing the number of low-skilled (level 1 to 3) persons needed in the group for each skill GPSK.

<u>LWEV</u> - a permanent attribute of GPSK describing the shortage (in number of men) of low-skilled persons (level 1 to 3) in the group GRP (or LOWN minus LOWA).

<u>MAN</u> - a temporary entity describing the men in the system. May be a member of the sets GRP, POOL, or CHNG. Owner of the set WRTH.

<u>MDEV</u> - a permanent attribute of GPSK describing the number of medium skilled (level 4 to 7) persons in GRP for each GPSK.

<u>MEDA</u> - an attribute of GPSK describing the number of medium skilled (level 4 to 7) persons in GRP for each GPSK.

<u>MEDN</u> - a permanent attribute of GPSK describing the number of medium skilled (level 4 to 7) persons needed in the group GRP for each GPSK.

<u>NAME</u> - a temporary attribute of SKIL equal to the index number of that skill. This value is an integer ranging from 1 to the number of skills (NGPSK).

<u>NAPP</u> - a permanent system variable equal to the number of men who will apply each period ETAP.

<u>NGEN</u> - a permanent system variable indexed by one in the program to generate identification numbers for men. ID(MAN) = NGEN

<u>NMEN</u> - a local variable used in exogenous event GPST which equals the number of men initially in the group GRP.

<u>NQIT</u> - a permanent system variable denoting the number of MEN who may leave the group each time event QUIT is executed.

<u>PBQ</u> - a permanent system variable equaling the probability that a man will quit each time endogenous event QUIT is executed.

<u>POOL</u> - a set with members MAN. In general, it contains the men who have applied to work in the group in the last two time periods ETAP. NPOOL is the number of MAN's in POOL. SPOOL and PPOOL are attributes of the temporary entity MAN, describing his successor and predecessor in POOL. FPOOL and LPOOL are systems variables which equal the first and last members of POOL. POOL is a ranked set, ranked on the attribute ID of MAN, with the lowest values of ID first.

<u>PROB</u> - a temporary attribute of MAN used in calculations of the probability of quitting for each MAN in GRP.

<u>RANM</u> - a system-generated variable generating a random number from zero to one (floating point) each time it is called.

RVAR - a random variable specified in the initialization form which takes on normal integer values from 1 to 10 with a mean of 5, each time it is called.

SKIL - a temporary entity describing the skills of each MAN in the system. Each SKIL is a member of the set WRTH(MAN) for some MAN in the system.

TAPP - a temporary attribute of MAN describing the time at which he applied to the group.

THIR - an attribute of MAN describing the time at which he was hired into the group. If not hired, THIR(MAN) = 0.

TIME - a system-generated variable containing the current simulated time of the system.

TPR - a local variable used in endogenous event QUIT, used in calculating the probability of a man leaving the group GRP.

TQIT - a temporary attribute of MAN describing the time at which he quit the group.

WRTH - a set with members SKIL. The owner of the set is MAN (WRTH(MAN)), and each set describes the skills which the MAN possesses. NWRTH denotes the number of skills which each man possesses and in this program is always equal to GPSK. FWRTH and LWRTH are attributes of MAN. SWRTH is an attribute of SKIL. This set is FIFO.

X - a local variable used in endogenous event QUIT used in determining which, if any, MAN will leave the GRP each ETQT.

Y - a local variable used in endogenous event QUIT used to determine which, if any, MAN will leave the GRP each ETQT.

REFERENCES

Argyris, Chris. Organization and Innovation. Homewood, Illinois: Richard D. Irwin, 1964.

Biddle, Bruce J. "Roles, Goals and Value Structures in Organizations." Cooper, W. W., Leavitt, H. J., and Shelly II, M. W. (Eds.). New Perspectives in Organization Research. New York: John Wiley and Sons, Inc., 1964.

Blau, Peter M. and Scott, W. Richard. Formal Organizations. San Francisco, California: Chandler Publishing Company, 1962.

Boguslaw, Robert. The New Utopians. Englewood Cliffs, New Jersey: Prentice-Hall, 1965.

Clarkson, Geoffrey, P. E. "A Model of the Investment Process." Feigenbaum, Edward A. and Feldman, Julian (Eds.). Computers and Thought. New York: McGraw-Hill, 1963.

Collins, Barry E. and Guetzkow, Harold. A Social Psychology of Group Processes for Decision-Making. New York: John Wiley and Sons, Inc., 1964.

Cyert, R. M. and March, J. G. A Behavioral Theory of the Firm. Englewood Cliffs, New Jersey: Prentice-Hall, 1963.

deSola Poole, Ithiel and Abelson, Robert. "The Simulmatics Project." Guetzkow, H. (Ed.). Simulation in Social Science Readings. Englewood Cliffs, New Jersey: Prentice-Hall, 1962.

Forrester, Jay W. Industrial Dynamics. Cambridge, Massachusetts: Wiley-MIT Press, 1961.

Goode, H. H. and Machol, R. E. Systems Engineering. New York: McGraw-Hill, 1957.

Guetzkow, Harold, "A Use of Simulation in the Study of Inter-Nation Relations." Guetzkow, H. (Ed.). Simulation in Social Science Readings. Englewood Cliffs, New Jersey: Prentice-Hall, 1962.

Gullahorn, John T. and Gullahorn, Jeanne E. "Some Computer Applications in Social Science." American Sociological Review. Vol. 32, No. 3. June, 1965.

Hitch, C. J. and McKean, R. N. Economics of Defense in a Nuclear Age. Cambridge, Massachusetts: Harvard University Press, 1960.

March, James G., Simon, Hubert A., and Guetzkow, Harold. Organizations. New York: John Wiley and Sons, Inc., 1958.

McGrath, Joseph F. "Toward Theory of Method for Research on Organizations." Cooper, W. W., Leavitt, H. J., and Shelly II, M. W. (Eds.). *New Perspectives in Organization Research*. New York: John Wiley and Sons, Inc., 1964.

Mesarović, M. D., Sanders, J. L., and Sprague, C. F. "An Axiomatic Approach to Organizations from a General Systems Viewpoint." *New Perspectives in Organization Research*. New York: John Wiley and Sons, Inc., 1964.

Morgenthaler, George W. "The Theory and Application of Simulation." Ackoff, R. L. (Ed.). *Progress in Operations Research*. New York: John Wiley and Sons, Inc., 1964.

Orcutt, Guy H.; Greenberger, Martin; Korbel, John: and Rivlin, Alice M. *Microanalysis of Socioeconomic Systems - A Simulation Study*. New York: Harper and Brothers, 1961.

Rath, G. J. and Rubenstein, A. H. "Establishing New R and D Skills." 1964 Joint Meeting, Operations Research Society of America and The Institute of Management Sciences. Minneapolis, Minnesota. October 9, 1964. Unpublished Talk.

Roberts, E. B. *Engineering Dynamics and Productivity on Research and Development Projects*. Working Paper: Organization Research Program. A. P. Sloan School of Industrial Management, Massachusetts Institute of Technology.

Rome, Sidney C. and Rome Beatrice K. "Computer Simulation Toward a Theory of Large Organizations." Borko, Harold (Ed.). *Computer Applications in the Behavior Sciences*. Englewood Cliffs, New Jersey: Prentice-Hall, 1962.

Rubenstein, A. H. and Radnor, M. "Rôle de la direction generale dans les programmes de recherche des grandes compagnies decentralisées." Actes de la 3ème Conférence Internationale de Recherche Opérationnelle, Oslo, 1963. Paris: Dounod, 1964.

Schroeder, Roger G. and Rath, Gustave J. "The Role of Mathematical Models in Educational Research." *Psychology in the Schools*. October, 1965.

Shelly II, Maynard W. "Memo to Participant in the Conference on the Management of the Research and Development Laboratory." February 10, 1965. Ditto.

Shelly II, Maynard W. (Ed.). *The Research Society*. New York: John Wiley and Sons, Inc. (In Press).

Tannenbaum, Robert, Weschler, Irving R., and Massarik, Fred. *Leadership and Organization*. New York: McGraw-Hill, 1961.

A Directory of Research-on Research. College on Research and Development (COLRAD) of The Institute of Management Sciences (TIMS). May, 1964.

United States Air Force. Configuration Management During Definition and Acquisition Phases. AFSCM 375-1. Air Force Systems Command. Andrews Air Force Base, Washington, D. D. June 1, 1964.